Space Technology Research Grants

Optimal Aerocapture Guidance

Completed Technology Project (2015 - 2016)

Project Introduction

The main goal of my research is to develop, implement, verify, and validate an optimal numerical predictor-corrector aerocapture guidance algorithm that is applicable to a wide range of vehicle configurations and lifting capabilities, and to different missions from orbital and suborbital atmospheric entry to aerocapture. The algorithm will be capable of effectively enforcing trajectory constraints on heating rates and aerodynamic load, and will also be flexible to accommodate further mission considerations such as maximization of apogee velocity for aerocapture missions. The algorithm framework and core software part will be the same if the algorithm is reconfigured to produce an advanced entry guidance algorithm. Testing of the algorithm will be carried out through the use of extensive simulations in a NASA high-fidelity simulation environment. A two-phase optimal aerocapture guidance algorithm will be developed using closed-loop guidance to minimize the required delta V to establish the desired final orbit. A numerical predictor-corrector will perform on-board calculations to determine the switching time that produces the optimal flight to satisfy the desired conditions and minimize the required delta V. This algorithm will use the optimal bang-bang bank angle profile structure, in which the vehicle first flies with the lift force pointed straight up, and then flies full lift-down until it exits the atmosphere. The optimal trajectory is found by determining the time at which the vehicle switches between full lift-down flight and full-lift up flight. The predictor-corrector algorithm will play the role of on-board trajectory planner where a feasible trajectory is planned periodically based on the current condition and target condition, at a much lower frequency. Between the trajectory updates, the trajectory-tracking guidance will track the planned trajectory and provide the guidance commands. Such a hybrid approach could retain the main benefits of both approaches: the adaptive capability of the predictor-corrector algorithm and the low computational requirement of trajectory-tracking guidance. The design of the trajectory tracking guidance law will be accomplished by the Linear Quadratic Regulator (LQR) approach. This feature is very important to the proposed hybrid approach because it means that a single LQR tracking law will be applicable to all reference trajectories generated/updated by the predictor-corrector algorithm. This project will investigate the effectiveness of this hybrid approach and compare it with fully numerical predictor-corrector guidance and trajectory-tracking (only) guidance approaches. No other existing aerocapture guidance algorithms have the capability to ensure truly optimal performance in terms of minimum post-exit orbital insertion delta V. This novel algorithm allows for reliable optimal solutions to nonlinear, constrained control problems. The algorithm is also innovative in that it is the first that is optimal based on the optimal control theory, and therefore could offer a potentially significant advantage in reducing propellant consumption for aerocapture missions. An algorithm of this type would significantly reduce or even eliminate the need for the design and implementation of different guidance algorithms for different vehicles and aeroassist missions, including entry guidance. In addition, the load factor and heating constraints can be

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Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Iowa State University

Responsible Program:

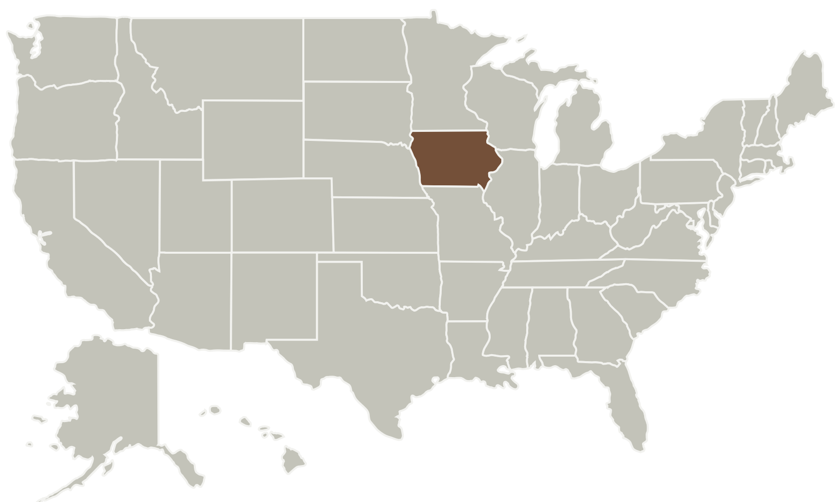
Space Technology Research Grants

observed directly, unlike current available entry guidance algorithms such as the Apollo or Space Shuttle entry guidance approaches.

Anticipated Benefits

No other existing aerocapture guidance algorithms have the capability to ensure truly optimal performance in terms of minimum post-exit orbital insertion delta V. This novel algorithm allows for reliable optimal solutions to nonlinear, constrained control problems. The algorithm is also innovative in that it is the first that is optimal based on the optimal control theory, and therefore could offer a potentially significant advantage in reducing propellant consumption for aerocapture missions. An algorithm of this type would significantly reduce or even eliminate the need for the design and implementation of different guidance algorithms for different vehicles and aeroassist missions, including entry guidance. In addition, the load factor and heating constraints can be observed directly, unlike current available entry guidance algorithms such as the Apollo or Space Shuttle entry guidance approaches.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Iowa State University	Lead Organization	Academia	Ames, Iowa

Project Management

Program Director:
Claudia M Meyer

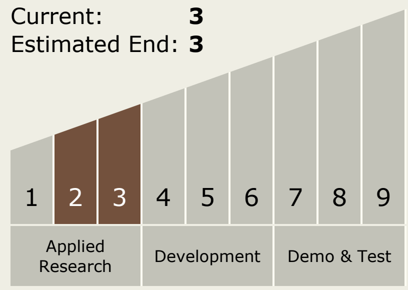
Program Manager:
Hung D Nguyen

Principal Investigator:
Ping Lu

Co-Investigator:
Kyle D Webb

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**



Technology Areas

Primary:

- TX09 Entry, Descent, and Landing
  └ TX09.4 Vehicle Systems
    └ TX09.4.7 Guidance, Navigation and Control (GN&C) for EDL

Target Destination

Mars

Primary U.S. Work Locations
Iowa

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html